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To cite this article: B Soust-Verdaguer *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **588** 022008

IOP Conf. Series: Earth and Environmental Science **588** (2020) 022008 doi:10.1088/1755-1315/588/2/022008

Implications of using systematic decomposition structures to organize building LCA information: A comparative analysis of national standards and guidelines- IEA EBC ANNEX 72

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Abstract. **Introduction:** The application of the Life Cycle Assessment (LCA) technique to a building requires the collection and organization of a large amount of data over its life cycle. The systematic decomposition method can be used to classify building components, elements and materials, overcome specific difficulties that are encountered when attempting to complete the life cycle inventory and increase the reliability and transparency of results. In this paper, which was developed in the context of the research project IEA EBC Annex 72, we demonstrate the implications of taking such approach and describe the results of a comparison among different national standards/guidelines that are used to conduct LCA for building decomposition. **Methods:** We initially identified the main characteristics of the standards/guidelines used by Annex participant countries. The "be2226" reference office building was used as a reference to apply the different national standards/guidelines related to building decomposition. It served as a basis of comparison, allowing us to identify the implications of using different systems/standards in the LCA practice, in terms of how these differences affect the LCI structures, LCA databases and the methods used to communicate results. We also analyzed the implications of integrating these standards/guidelines into Building Information Modelling (BIM) to support LCA. **Results:** Twelve national classification systems/ standards/guidelines for the building decomposition were compared. Differences were identified among the levels of decomposition and grouping principles, as well as the consequences of these differences that were related to the LCI organization. In addition, differences were observed among the LCA databases and the structures of the results. **Conclusions:** The findings of this study summarize and provide an overview of the most relevant aspects of using a standardized building decomposition structure to conduct LCA. Recommendations are formulated on the basis of these findings.

1. Introduction

Buildings and the construction industry are responsible of almost 40% of energy-related CO_2-e emissions and 35% of the global final energy use. Thus, considering current construction practices and their growing tendencies, researchers and practitioners can take advantage of a critical window of opportunity and address climate change mitigation goals by reducing the impacts of buildings and construction [1,2].

The Life Cycle Assessment (LCA) technique is used to calculate the potential environmental impacts caused by a product such as a building. The method described in ISO-14040 [3], ISO-14044 [4] and particularly in EN-15978 [5] (adaptation to buildings) can be applied to define the scope of the study, identify the life cycle stages scenarios to be considered and determine the calculation procedure [5]. However, aspects such as the building information structure and the systematic building decomposition (i.e., decompose into systems and building components) are not defined. Considering this gap as a research opportunity, our aim in this paper is to show that integrating a systematic building decomposition for LCA purposes can improve the transparency and reliability of the assessment results and provide other benefits. In doing so, this study supports the achievement of the UN Sustainable Development Goals (SDG) number 12 (Responsible consumption and production), 13 (Climate action) as well as (Sustainable Cities and Communities).

The present paper is based on discussions that arose and contributions that were to the ongoing international research project IEA EBC Annex 72 "Assessing Life Cycle Related Environmental Impacts Caused by Buildings." The project "*is researching harmonization issues arising when applying LCA approaches on buildings*" [6], that are developed in five main subtasks. The present paper was developed in the context of Subtask 2 (ST2), which is dedicated to building assessment workflows and tools, with "*focus on the analysis and outlook of national or regional state-of-the-art building assessment tools, the integration of environmental information in planning tools and requirements in different planning phases with focus on LCA and BIM*" [6].

In this paper, we present and compare different national approaches that are taken to perform systematic building decomposition from the viewpoint of building LCA information management. A reference building (be2226) [7,8] was used to illustrate the main differences and similarities among the national approaches. Finally, based on these findings, recommendations were made that contribute to check and communicate the completeness of the building description, improvement the transparency and comparability of LCA results, and allow the LCA application to be integrated into Building Information Modelling (BIM).

2. Background

2.1. Systematic building decomposition for LCA application

Authors of the current literature have recognized that a large amount of data and calculations are involved in a building's LCA [9]. To facilitate the processes of collecting these data and performing these calculations, a building can be decomposed into a number of "portions," "component groups," "elements," products, materials, typologies and fabricants [9]. To decompose a building into different "portions" (e.g., systems, parts, components, elements, materials), these must be identified and grouped according to specific criteria or a specific structure. By using a systematic approach to decompose the building into portions, researchers can improve the organization and identification of the building parts, which ultimately helps guide and standardize the overall process.

2.2. Classification systems for building decomposition purposes

A systematic building decomposition to conduct LCA can be performed by using classification systems [10,11]. A classification system is applied to sort series of objects into different classes, members of which have specific properties [12,13]. Cavalliere et al. [10] demonstrated the potential to use a hierarchical, systematic method of decomposing the building, relating the design phases (in BIM) with the level(s) of hierarchy that are applied to organize the Bauteilkatalog, according to the Swiss code eBKP-H (SN 506 511) [14]. Hollberg et al. [11] used the same Swiss code [14] to decompose the building elements while determining LCA benchmarks. Röck et al. [15] highlighted the relevance of using a data structure and a naming convention that were based on a systematic approach (e.g., Omniclass [16], Uniclass [17], Uniformat [18], mostly based on ISO 12006-2 [19]) to conduct LCA, especially when coupled with BIM.

The act of decomposing is "to break, or to break something, into smaller parts" [20], and the classification can be defined as "the act or process of dividing things into groups according to their type" [19,20]. Relating both concepts to the building field suggests that a classification system can be effectively applied to organize information and develop a systematic approach to decomposition.

Tables and data structures are used to organize different aspects of the building's information during its life cycle. As different stakeholders are interested in different properties and information, all classifications are based on specific properties and purposes, for example, placing a focus on cost estimation, management and operating activities. Another relevant aspect of the classification systems are the naming codes and grouping principles used. The naming codes or naming convention are the rules that are used to name the different systems and group of parts, and the grouping principles are the rules or criteria that are used to organize and classify these items.

2.3. Classification systems for building decomposition in BIM

The relevance of using classification systems in BIM has been clearly highlighted in the literature [21–23]. Authors have recognized the challenge involved in integrating structures/tables that are based on the classification and identification of objects in digital tools, such as BIM. These structures/tables, however, can provide a common language, a structure for building decomposition and more uniform and transparent means of information management, among other things [21]. In addition, one of the main advantages of using classification systems in BIM is that it offers the possibility to integrate naming codes that can be used to organize and manage the building elements/objects that compose the model.

3. Methods

The study begins by offering an overview of the standards/guidelines for building decomposition used by IEA EBC Annex 72 participant countries. The office building "be2226" [24] was used as a basis to illustrate the differences and similarities in the organization of building parts, and to analyze the implications of using those national standards/guidelines to organize the building information relevant for LCA, including the organization of the Life Cycle Inventory (LCI), LCA databases and results communication. The authors also analyzed the implications of integrating these standards/guidelines into BIM for LCA purposes.

3.1. Overview of national standards for building decomposition

National standards or guidelines for building decomposition to conduct LCA used in twelve countries participating in the IEA EBC Annex 72 are analyzed: Austria, Belgium, Brazil, Canada, Czech Republic, France, Germany, the Netherlands, New Zealand, Spain, Switzerland and the United Kingdom (Table 1).

Table 1. National standards and guidelines for building decomposition used to organize LCA information in twelve countries participating in the IEA EBC Annex 72 (source: Prepared by the authors based on national regulations in classification systems).

Country	Standard or guideline based on	Main purpose
Austria	ÖNORM B1801 [25]	Building construction cost estimation and LCA data structure.
Belgium	BB/SfB plus [26]	Classification and coding system, building construction cost estimation and LCA data structure.
Brazil	ABNT NBR 15575 [27]	Building performance (also suitable for construction cost estimation and LCA data structure)
Canada	UNIFORMAT II Elemental Classification (E1557-97) [18]	Building specifications, cost estimating, cost analysis and LCA data structure.
Czech Republic	Not specified – *ad-hoc table*	LCA data structure
France	EQUER model [28]	LCA data structure and energy demand calculation
Germany	DIN 276 [29] DIN 18960 [30]	Building construction, cost estimation, (LCA data structure).
The Netherlands	NL/SfB	Building construction, cost and LCA data structure
New Zealand	Uniclass 2015 [17]	Building construction, cost estimation and LCA data structure.
Spain	CTE [31] (Spanish Building Technical Code) and *BBCA* [32]	Building construction, cost estimation and LCA data structure.
Switzerland	SN 506 511 [14]	Building construction, cost estimation and LCA data structure.
UK	SFCA [33]	Building construction, cost estimation and LCA data structure.

3.2. Brief description of the case study reference building

The "be2226" office building is located in Lustenau (Austria) and was previously used within the IEA EBC Annex 72 project as a reference building to compare national LCA methods, as reported in [24]. For the present study, the same template information developed for [24] was used to apply different national classification systems and standards/guidelines for the building decomposition and organize the building information. This template encompasses the following building element types: foundation, external walls, floor structure, roof structure, stairs, flooring, roofing, windows, doors and building services.

4. Results

The results presented are based on the tables and data structures obtained from the application of the national standard/guidelines to the building decomposition of the reference building "be2226."

4.1. Tables and data structures

ISO 12006-2 [19] provides recommendations for the development of classification systems and tables to organize building information. Specifically, the level "order of specialisation" (classes and subclasses) and the level 'order of composition' allow users to hierarchically organize building parts.

In accordance with the ISO principles for classification and composition, we disaggregate the building parts into vertical levels and horizontal sub-division. Vertical decomposition allows for the subdivision or classification of a system into sub-systems using 'part-of' relations, while the horizontal decomposition allows the order of classes in sub-division determined by 'type-of' relations. Vertical levels and horizontal sub-division decomposition were used to compare and analyze a collection of national standards and guidelines for building decomposition.

The tables and data structures summarize the number of levels of vertical decomposition and sub-divisions of horizontal decomposition, that are considered to organize 'part-of' (vertical) and 'type-of' (horizontal) relations of the reference building "be2226." These tables and data structures also include a brief study of the naming codes/conventions and grouping principles.

Table 2. Number of vertical levels of decomposition and horizontal sub-divisions. (source: Prepared by the authors based on national regulation in construction and LCA application to buildings)

Nr of V-levels*	AT	BE	BR	CA	CH	CZ	DE	ES	FR	NL	NZ	UK
							Country code					
1	2 Shell, Core	3 Structure, Substructure and Services	6 Systems/elements: Structure Internal floors Façade Partitions Roof Plumbing	4 Major Group of Elements A Substructure, B Shell, C Interiors, D Services	4 Categories: C- Structure E- Envelope G- Interior. F- Roof D- Technical equipment	Not specified	2 Systems: 300 Structure construction works, 400 Structure – services	5[1] Systems: Structure; Envelope; Partitions; Finishing; Air conditioning and installations	3 Systems/ Categories: A Foundations; B Envelope; C Others	6 Category/System Foundations, Carcass, Finishing, Finishes; Installations E Fixed provisions	1 EE_Elements and functions	5 Category/Systems 1 Substructure 2 Superstructure 3 Finishes 4 Fittings, furnishings and equipment (FF&E) 5 Building services/MEP
2	7 Building parts: Foundation Substructure; Load bearing structural frame; Non load bearing elements, Facades; Roof, Fittings and furnishings, Other_systems	6 Group of Elements: 1. Ground substructure 2. Structure primary elements, carcass 3. Secondary elements of superstructure 4. Finishes to structure 5. Services mainly electrical 6. Loose furniture equipment	14 Building parts: Main structure; Complementary structure; Façade; Internal partitions; Roof; Internal finishing; Façade finishing; External flooring; Painting; Waterproof system; External windows and doors; Internal windows and doors; Building services; Equipment	8 Group of Elements: A10 Foundations; B10 Superstructure B20 Exterior Closure; B30 Roofing C10 Interior Construction; C20 Staircases C30 Interior Finishes Conveying E20 Furnishings	10 Building elements: 1. Foundation 2. Stairs 3. Exterior wall above ground 4. Window 5. Floor 6. Roof 7. Interior wall 8. Ceiling 9. Technical equipment 10.Sanitary equipment	14 Building parts: Foundation Waterproofing layers Vertical and horizontal construction elements Roof construction Roof deck Staircase Internal partitions Non-bearing cladding Finishes Final floor covering Windows and doors	8 Building parts: 320 Foundations, 330 External walls, 340 Internal walls; 350 Floor and callings; 360 Roofs; 370 Structural fitments; 460 Transport systems	9[2] 03. Foundations 05. Structure 06. Masonry 07. Roof 08. Installations 09. Isolations 10. Finishing 11. Carpentry and safe and security elements 12. Glass	9 Building parts: A Foundations; B1 Exterior walls B2 Interior walls B3 Windows and doors B4 Ground floors B5 Intermediate floors B6 Roofs C Sanitary Equipment Transports	16 Groups of Elements: Floors on foundation; Foundational construction; External walls; Inner walls; Floors; Stairs and inclines; Roofs Main supporting construction; Exterior wall openings; Interior wall openings; Exterior wall finishes; Interior wall finishes; Floor finishes; Ceiling finishes; Roof finishes; Transportation	6 EF_ Structural elements Wall and barrier elements Roofs, floor and paving elements Stairs and ramps Signage, fittings, furnishings and equipment Transport functions	13 Groups of Elements: 1.1 Substructure 2.2 Upper floors incl. balconies 2.3 Roof 2.4 Stairs and ramps 2.5 External Walls 2.6 Windows and External Doors 2.7 Internal Walls and Partitions 2.8 Internal Doors 3.1 Wall finishes 3.2 Floor finishes 3.3 Ceiling finishes 4.1 Fittings, Furnishings & Equipment 5.1–5.14 Services incl. Building-related
3	16 Building elements type	18 Building elements type	-	18 Individual Elements	16 Building components	Not specified	16 Elements type	12 Building elements type	47 Materials	25 Building elements type	10 Building elements type	24 Building elements
4	26 Building elements	33 Building elements	-	52 Sub-elements	72 Materials	Not specified	27 Building elements	20 Building Element	-	31 Building elements	21 Building elements	42 Sub-elements
5	45 Building sub-elements	54 Sub-elements	-	69 Materials	-	Not specified	58 Sub-elements	53[2] Material	-	50 Sub-elements	48 Sub-elements	59 Materials
6	67 Materials	73 Materials	-	-	-	-	73 Materials	-	-	70 Materials	73 Materials	-

Number of H- Levels**

* Number of Vertical Levels of decomposition. ** Number of Horizontal Levels of decomposition. [1] Based on CTE [31] (Spanish Building Technical Code) primary classification. [2] Based on BBCA [32] Classification.

4.2. Table structures: number of levels of decomposition

Most standards or guidelines recommend integrating six vertical levels of decomposition (from the complete building level (level 0) to the material level (level 6)). These levels include a first level that integrates the general classification process applied to the building systems or categories, a second level composed by applying a classification of a group of elements, a third level composed by applying an elemental type classification, a fourth level composed by applying an elemental specific classification, a fifth level that integrates a sub-elemental classification and a sixth level that integrates a material classification process. In this case study ("be2226" reference building), the maximum number of materials detected as a result of the decomposition process was 73, which corresponds to the decomposition of 24 building specific elements (included in the BIM model) into 54 sub-elements, and finally into 73 materials.

The major differences were identified in terms of the organization of the first vertical level of the elements or systems classification (Table 2). At that level, the standards/guidelines examined could not be effectively applied to consider the same number of building groups of elements or their respective elements/sub-elements/materials and products. For example, the Austrian standard (see Figure 1) can be used to consider two major groups (Core and Shell), while the Swiss and Spanish codes respectively take into account four categories (Structure, Technical equipment, Envelope, Interior and Roof) or five systems (Structure; Envelope; Partitions; Finishing; Air conditioning and installations).

In most of the cases analyzed, the levels of desegregation and grouping principles from vertical levels 1–3 depended on the data structure that was defined by the standard/guideline for building decomposition. For levels 4–6 (building elemental classification), however, these mainly depended on the building characteristics and the granularity of the building model, i.e., the variety of element types/sub-elements and materials.

4.3. Table structures: grouping principles and naming codes

Results show differences in naming codes and conventions, following different criteria on the taxonomy and organization of the different levels of decomposition. These could be partly due to translation or local construction culture and meanings.

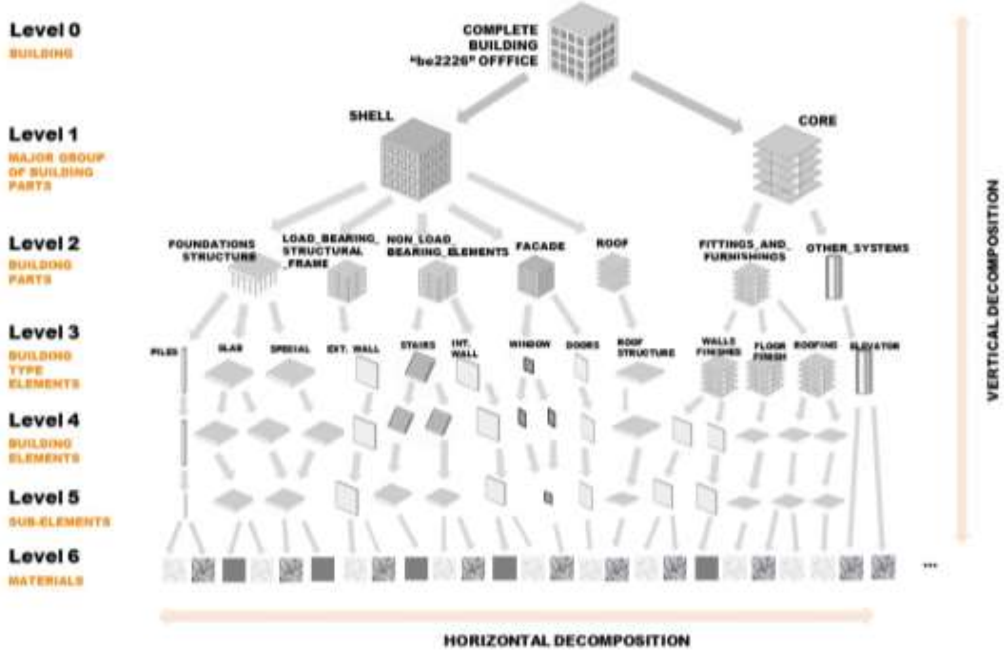

Figure 1. Scheme for reference building decomposition using the Austrian standard (source: prepared by authors based on ÖNORM B1801 [25]).

5. Discussion

The heterogeneity of the standards/guidelines used for building decomposition in the different countries studied became evident when they were applied to the reference building "be2226." The subsequent analysis and discussion of the results places a focus on two aspects: the implications of the use of these standards and guidelines for building decomposition for LCA purposes and their implications with respect to BIM-based design phases.

5.1 Implications regarding aspects of LCA

We detected differences in the organization of the building parts, the granularity or precision in the building decomposition, the sub-divisions and the levels of decomposition of the standards /guidelines across the different systems/standards. These influenced various aspects of the LCA, such as the structure of the LCI, LCA databases and communication of results.

The influence on the structure of the LCI potentially affects the ability to verify its completeness, because the LCI provides a standardized data structure for organizing and grouping the building parts. Thus, the more detailed and hierarchically organized the LCI is, the easier it is to identify the building parts/elements/sub-elements/materials. Regarding the communication of results, the influence mainly affects the ability to detect hotspots and optimize the environmental performance of the building parts/elements/sub-elements/materials. If more levels of vertical and horizontal decomposition are used, a more accurate building decomposition process can be carried out, but this approach also increases the complexity of the data structure, which is a significant drawback. Thus, to effectively communicate results, both aspects should be considered.

Our results also support the hypothesis that– the existence of several data structures (e.g., Austrian, German, Belgium, Dutch, Spanish, Swiss, France, UK) – created by the hierarchical decomposition of building systems or categories/building parts/elements/sub-elements/materials – can support an assessment in various design phases of the building. For example, this information can be used at the element level in an early stage and at the material level in a later stage), as previously proposed by Cavalliere et al. [10].

5.2 Implications for design phases in design tools (BIM)

One of the most relevant implications of integrating a systematic building decomposition into BIM is that it can provide specific rules which can then be applied to organize the building elements/objects. This aspect is also directly related to the granularity and level of definition. In BIM methodology, multiple levels of object definition are needed during the design development process [21]. In the early design phase, generic objects are required, while the detailed design phase requires objects with high granularity and defined object information [21]. The precision of the modelling also changes during the design process.

The results of this study confirm that the organization of the building elements/objects differed, and especially their hierarchy differed. For example, the French table used for building decomposition defines that the elements of the "Interior walls" contains the finishing materials (e.g., "B Envelope"→ "B2 Interior walls"→"B22 Finishes") in the "Envelope" system. The Austrian standard, however, treats the internal wall finishes as part of a separate group called "Wall and ceiling finishes" (e.g., "Core (fittings, furnishings and services)"→ "Fittings_and_furnishings" → "Wall and ceiling finishes"). This means that, the information about the object (e.g. "finish materials") was hierarchically grouped in the French table based on a principle associated with the object itself (e.g."Interior walls"), while the Austrian standard treated the object as a new sub-system (e.g., "Core (fittings, furnishings and services)") that contained all the building finishings (e.g., "Sanitary fittings, Ceilings, Wall and ceiling finishes, Floor coverings and finishes"). These types of differences were also detected when comparing other systems and elements/objects, such as the structure or the external walls. No matter which standards/guidelines are considered to be the most appropriate, our results indicate that the decomposition or desegregation level of the building elements/objects needs to mirror the way that the objects are organized in the model, especially when considering the different design phase in BIM [34]. Moreover, this organizational aspect should ideally be considered when performing other types of calculations (e.g., energy calculation) using the same BIM model (which could be developed, for example, by using the French table).

6. Conclusions

In this study, we performed a comparative analysis of twelve national standards as applied to a reference building and illustrated the implications of the findings regarding aspects of the LCA. Our results show that it is relevant to implement a systematic approach in building decomposition to conduct LCA, but they also demonstrate that the application of certain national standards or guidelines for building decomposition to conduct a LCA influences the results obtained. The observed differences are, at least in part, due to the existence of different national environmental reference databases of construction elements (such as the *Bauteilkatalog*), different national standards for building classification (such as BB/SfB-plus [26]) and different guidelines that are currently used by building professionals to organize building information for a certain purpose (such as the *BBCA*).

The authors recommend performing, whenever possible, a systematic building decomposition based on standards or guidelines that integrate hierarchical grouping principles to organize building information for LCA (especially in BIM) and to improve the transparency of LCA results. This will enable the description of which elements/objects are included or not in the study, among other relevant information. This study also enabled us to detect the existence of challenges related to the interoperability, translation and harmonization of available standards and guidelines for building decomposition to conduct LCA among European countries. These challenges must be addressed in future research.

Acknowledgments

The authors thank to the IEA EBC Annex 72 (http://annex72.iea-ebc.org) experts who provided useful input that enriched this research. The Spanish contribution authors were financially supported by the research project entitled "Development of a unified tool for the quantification and reduction of environmental, social and economic impacts of life cycle buildings in Building Information Modelling platforms (BIM)" (ref. BIA2017-84830-R). The Swiss contribution were financially supported by the Swiss Federal Office of Energy, project "Design-integrated Life Cycle Assessment using BIM (BIM-LCA)" (SI/501811-01). The Austrian contribution were financially supported by the Austrian Ministry for Transport, Innovation and Technology (BMVIT), IEA Research Cooperation via the Austrian Research Promotion Agency (FFG) Grant #864142. The Czech contribution have been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I, project No. LO1605 and within project INTER-EXCELLENCE No. LTT19022.

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